Incoherent Tune Measurement in the SNS Ring

Peter Cameron
Brookhaven National Lab

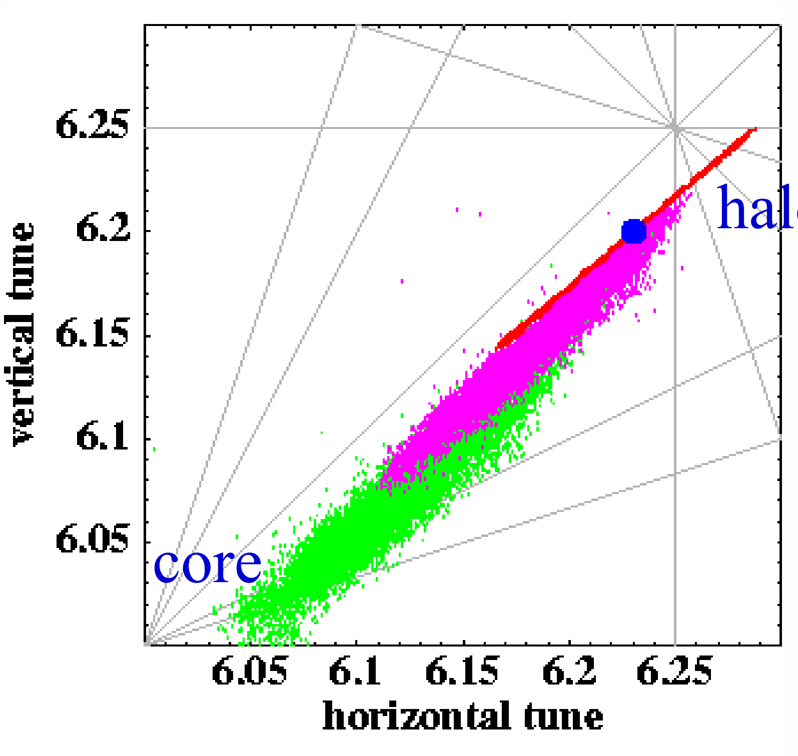
Outline

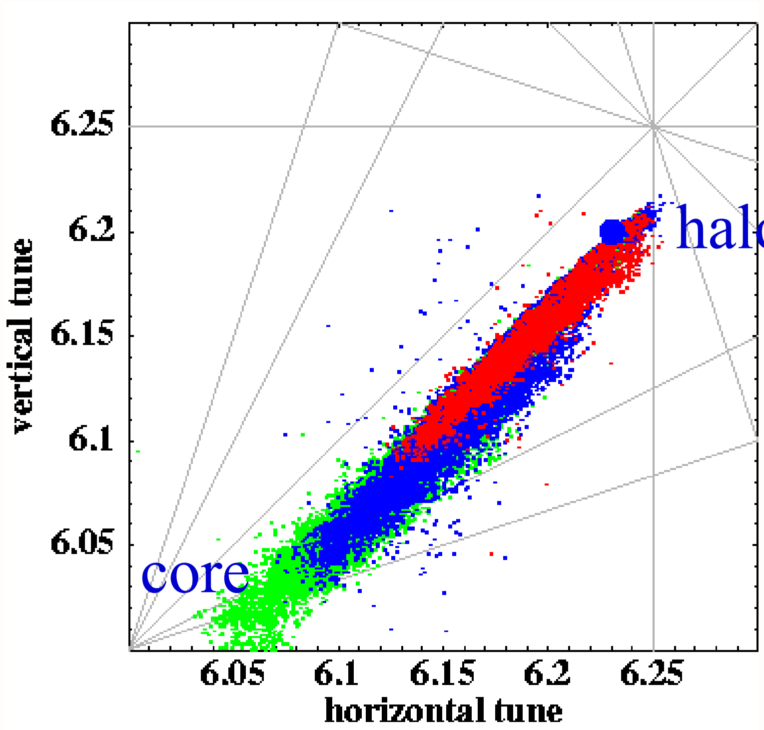
- Motivation
- Tune Footprints
- AP Requirements
- Tune Measurement Options
- Simulation
- Conclusions

Motivation

- Tune spread in high intensity machines is space charge dominated, with smaller contributions from chromaticity and uncompensated fringe fields
- Control of beam loss (and activation) requires control of tune footprint
- To control tune footprint it is very helpful to be able to measure it
- Additional information from tune measurement:
  - Electron cloud diagnostic
  - Halo diagnostic?
  - Resonance compensation, non-linearities compensation,…

Tune Footprints - blue dot is coherent tune





Footprints for 3 intensities (0.1, 1, and 2×10^{14}) at cycle end

Footprints after 263, 526, and 1060 turns, 10^{14} beam

AP Requirements for Tune Measurement

- What is ‘tune’ in a machine like SNS Ring?
- Coherent/Incoherent tune measurement spec
  - accuracy .001/.005
  - resolution .0005/.0025
- Both measurements should be binned (say 10-20 bins) thru the accumulation cycle
- Both measurements will require averaging over many pulses – e.g. resolution of .001 ideally requires 1000 turns, with 20 bins this requires 20,000 turns.

Ring Tune Measurement Options

1. Coherent Tune - Beam-in-Gap kicker, one or many BPMs
2. Incoherent Tune - 400 MHz electronics on some subset of Ring PUEs, measure tune of 400 MHz microbunches before decoherence
3. Incoherent Tune - Schottky
4. Incoherent Tune - HF kicker, Specialized Pickup
    - Premise is kick beam small subset of the beam distribution, similar to method 2 above
5. Incoherent Tune - Quadrupole Oscillations, common-mode dynamic range problem
6. Incoherent Tune - resonance crossing

Option 1 - Coherent Tune, Beam-In-Gap Kicker

Voltage = +/- 7KV   Aperture = 21cm

50 ohm stripline length = 4.5m

$\theta = 0.6$mrad $\beta = 15$m

Single kick amplitude (p-p) = 5mm

$\Delta p/p = .01$ $\xi = 8$

Chromatic Tune spread = $\xi \, \Delta p/p = .08$

Decoherence time about 12 turns

Multiple kicks and measurements to measure +/- .001

Δq_{coh} is difference between measured tunes at beginning and end of accumulation cycle

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Option 2 - Incoherent Tune, Injected microbunches

- Injected microbunches have coherent oscillations with spectral energy at 402.5MHz, and microbunch samples the space charge environment of the bunch, behaving like a big Schottky particle, so
- measure microbunch tune with some number of 402.5MHz modules
- Longitudinal debunching of 402.5MHz structure due to momentum spread is fast (a few turns)
- Measured incoherent tune can be correlated with measured amplitude of oscillation (how much can we play with the painting?), providing information about transverse distribution and tune footprint
- Can imagine a machine studies accumulation cycle with ~10 turns between injections at the time of interest, to avoid complication of random microbunch time jitter at injection
- **One** map of footprint will require ~ few thousand machine cycles

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Opt 3 - Schottky Signal Relative to RHIC Au

Power spectral density ~ $QNx^2q^2fk^2gSC/n\eta dp/p$

		RHIC	value	SNS	value
		Au		protons	
pickup Q		100	100	300	300
number of particles	N	6.00E+10	6.00E+10	1.00E+14	1.00E+14
beam size	x[mm]	1	1	20	400
charge quantum	q[coul]	1.26E-17	1.5876E-34	1.60E-19	2.56E-38
revolution frequency	f[Hz]	78000	78000	1.00E+06	1.00E+06
wave number	k[1/m]	1	1	0.2	0.04
geometric factor	g	1	1	0.6	0.6
space charge factor	SC	1	1	0.2	0.2
1/harmonic number	1/n	0.00033	0.00033	0.02	0.02
1/slip factor	1/eta	143	143	5	5
1/momentum spread	1/dp/p	1000	1000	100	100
			3.50E-15		1.47E-14
relative S/N	4.2				

Option 3 - RHIC LF Schottky at Injection

Span 78KHz

5dB/div

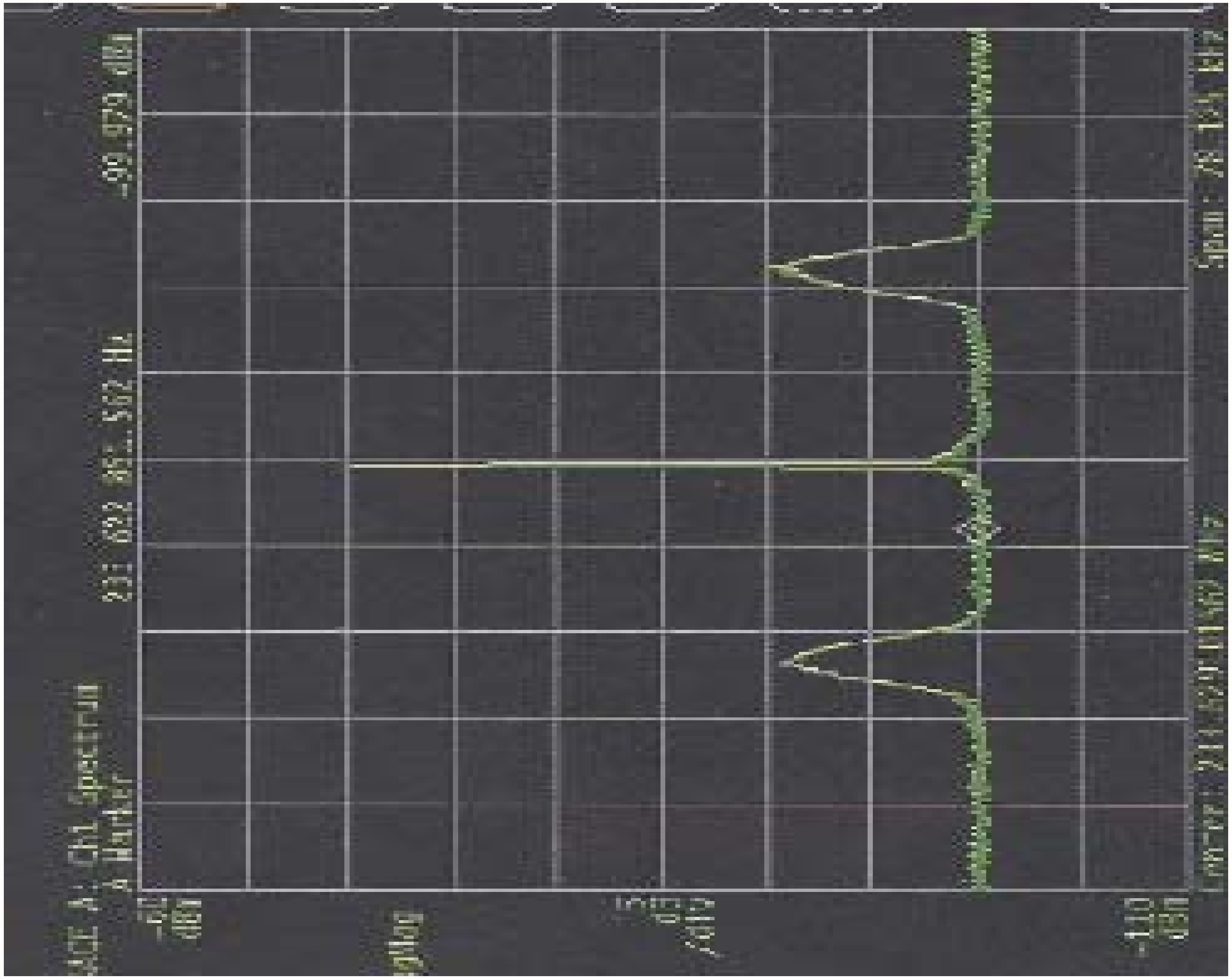
$\delta q = \eta N \delta p/p$

~ 2 KHz

$\eta \sim .007$

$N \sim 3060$

$\delta p/p \sim .001$



Option 3 - Resonant BPM

- M. Kesselman et al - PAC 2001
- Stub-tuned 1/4 wave resonator
- Simulated in Spice
- frequency ~ 240MHz (8.5xRF)
- Q_{loaded} ~ 100 optimal coupling
- In-tunnel hybrid for Σ and Δ
- Resonate difference mode - not sum mode signal at revolution line
- Moveable - minimize difference mode signal at revolution line
- Resonate above coherent spectrum

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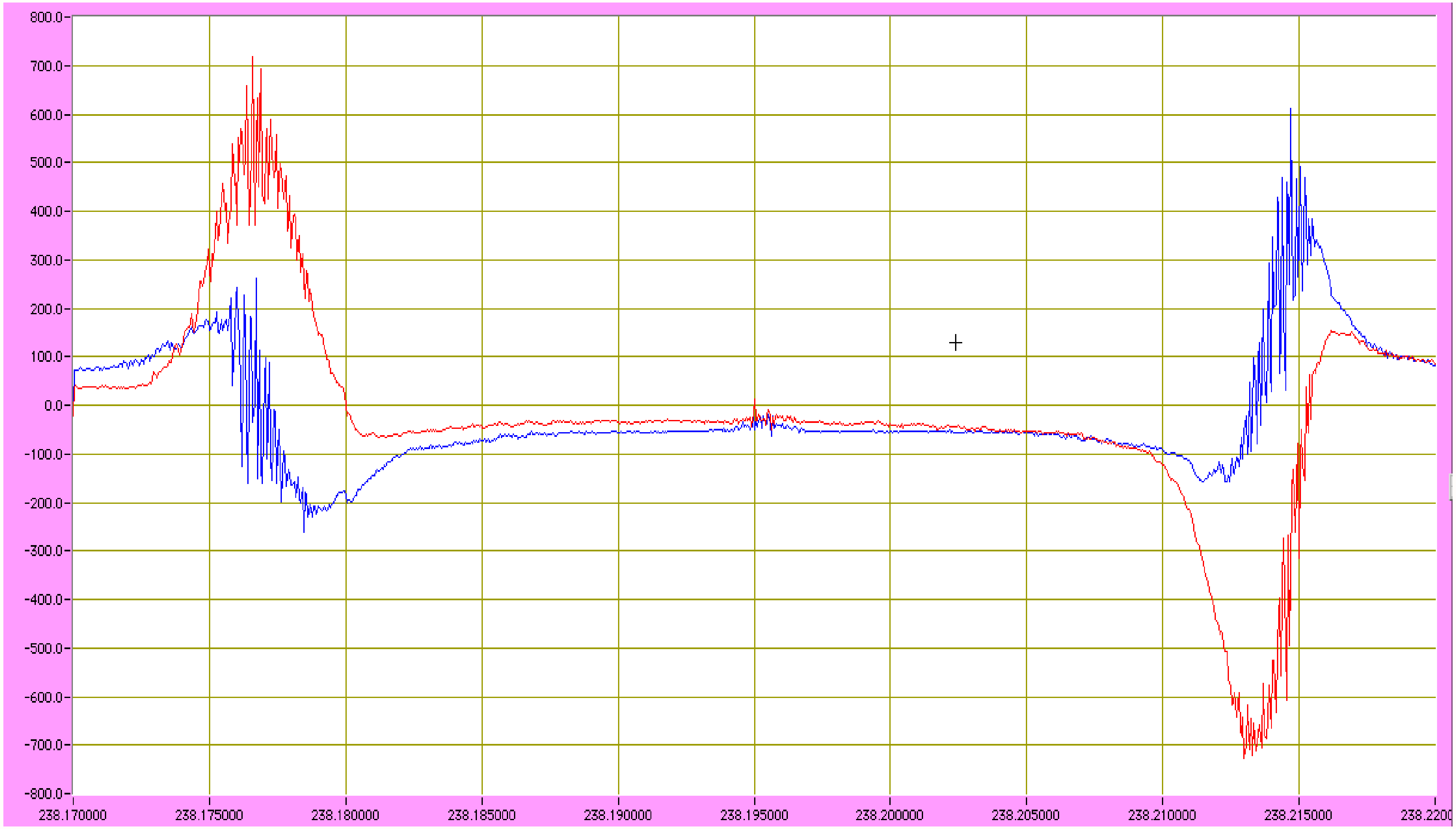
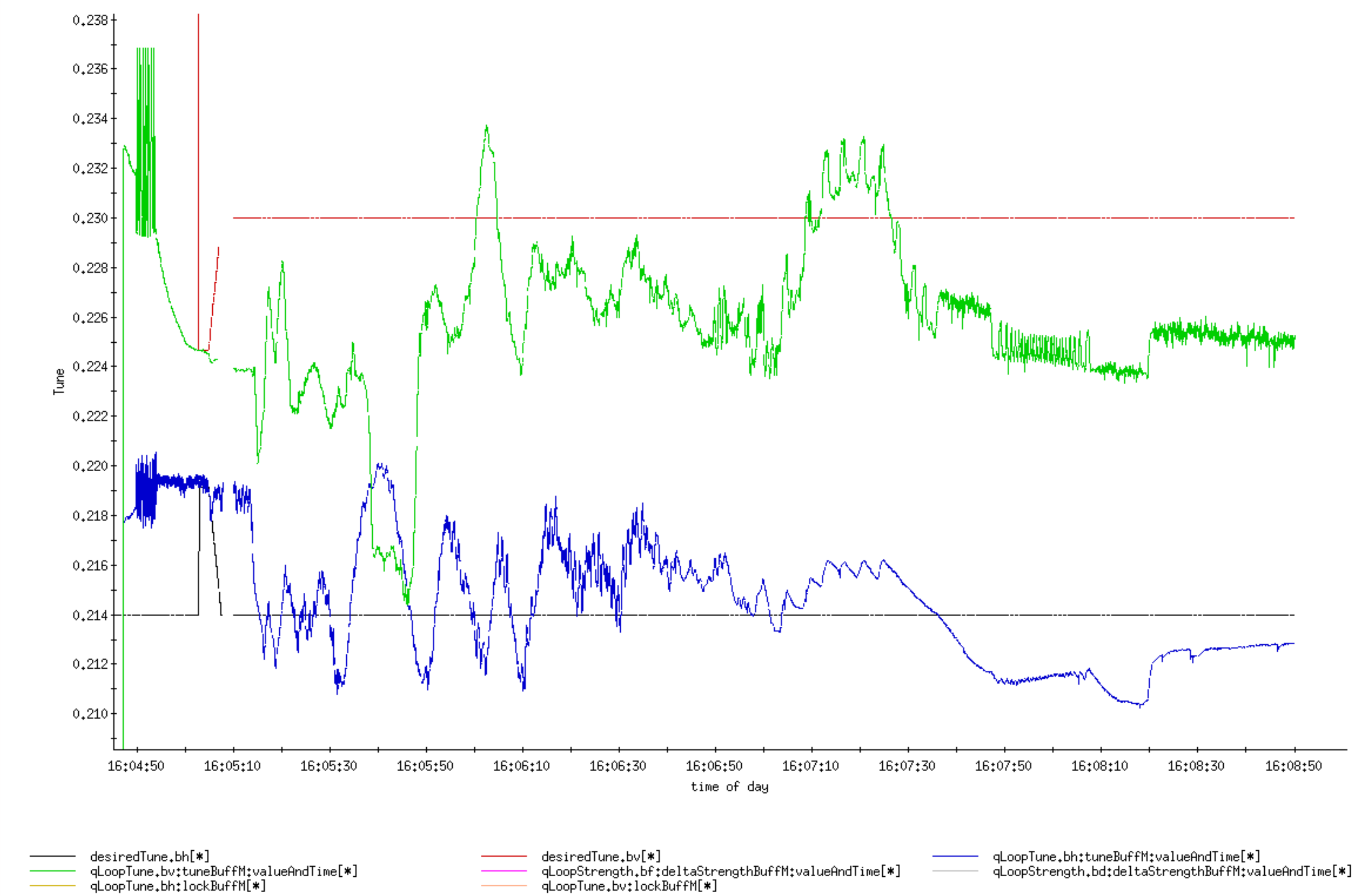
Opt 4 - Incoherent Tune - HF kicker, Specialized Pickup

- Beam Transfer Function Measurement - Drive beam at one selected frequency for an accumulation cycle, change frequency, repeat,…
- We kick small subset of beam tune distribution. Selected by
  - Incoherent amplitude – space charge
  - Momentum spread - chromaticity
- Result is similar to what you get from observing injection oscillations - ‘Enhanced’ Schottky Signal
- Incoherent because space charge tune shift is particularly sensitive to local coherence - chromaticity selects momentum, space charge selects transverse emittance
- Use resonant transverse pickup to improve sensitivity, reduce common-mode dynamic range problem
- Resonate above coherent spectrum to reduce common-mode dynamic range problem, use moveable BPM,…

Option 4 - RHIC Beam Transfer Function



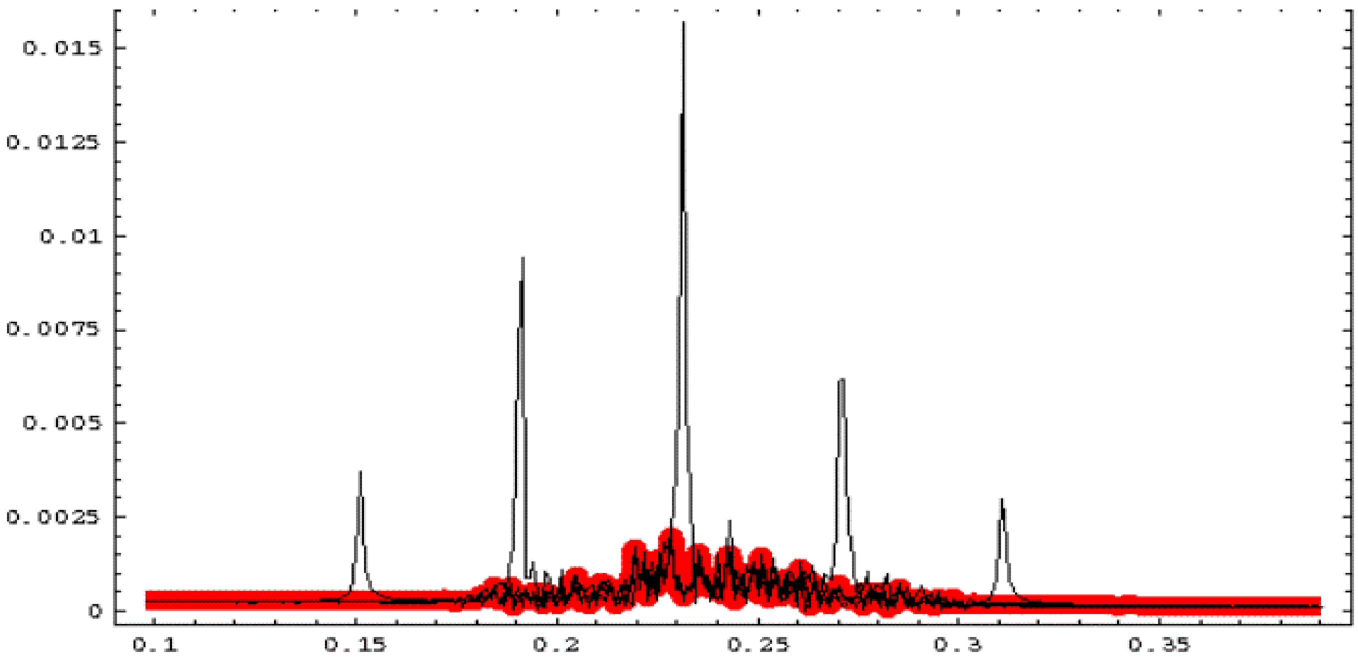
Option 4 - RHIC Beam-Beam Tune Shift



Option 4 - RHIC Beam-Beam Tune Shift

Option 4 - UAL Simulation – Preliminary result

Beam response (without space charge) to narrowband kick continuous thru accumulation cycle. Each peak corresponds to one cycle. Result is reasonable picture of tune spread due to chromaticity



Option 4 - Linewidths, Chromaticity,Space Charge,…

Sensitivity to excitation requires observation above coherent spectrum. Reasonable frequency would be 40-50 MHz. Tune spreads due to chromaticity ($f_0\xi\delta p/p$) and revolution harmonic ($f_0 n\eta\delta p/p$) cancel at the lower sideband about 40MHz for nominal SNS conditions, leaving only the space charge contribution.

$\mathrm{deltap} := 7\cdot 10^{-3}$ $\quad \eta := 0.2 \quad q := .23 \quad f_0 := 1\cdot\mathrm{MHz}$

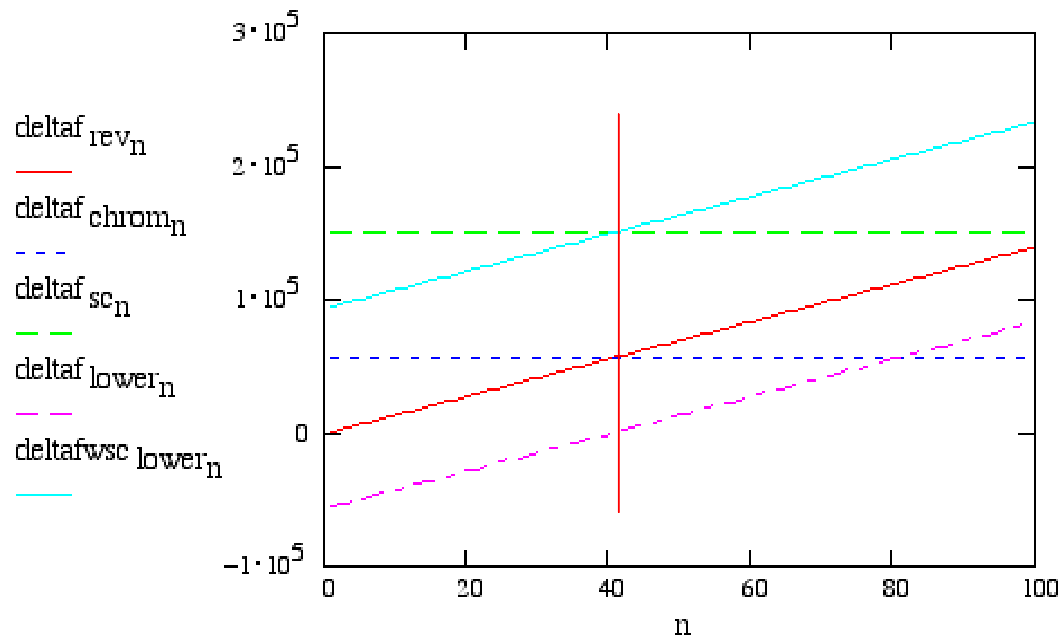
$\xi := 8 \quad \mathrm{deltaq}_{sc} := 0.15 \quad n := 1..100$

frequency spreads: $\mathrm{deltaf}_{rev_n} := n\cdot\eta\cdot\mathrm{deltap}\cdot f_0$

$\mathrm{deltaf}_{chrom_n} := \xi\cdot\mathrm{deltap}\cdot f_0 \qquad \mathrm{deltaf}_{sc_n} := \mathrm{deltaq}_{sc}\cdot f_0$

$\mathrm{deltaf}_{lower_n} := [(n-q)\cdot\eta - \xi]\cdot\mathrm{deltap}\cdot f_0$

$\mathrm{deltafwsc}_{lower_n} := [(n-q)\cdot\eta - \xi]\cdot\mathrm{deltap}\cdot f_0 + \mathrm{deltaq}_{sc}\cdot f_0$



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Option 5 - Incoherent Tune - Quadrupole Oscillations

- Method specifically developed (at CERN) to measure incoherent tune shift for high intensity beams. Measure quadrupole oscillations with specialized kicker and pickup
- All of the previous methods of measuring incoherent tune bear some relation to each other, are either Schottky or quasi-Schottky. Quadrupole oscillations will provide useful alternative measurement.
- This year's BIW Faraday Cup went to Quadrupole Monitor
- To build a good quadrupole monitor is not trivial

Basic Method - Quadrupole Oscillations

Incoherent tune shift in x plane is related to measured quadrupole frequency by:

$Q_2 = 2Q_0 - (1.5\text{-}0.5a_x/(a_x+a_y))\delta Q_{inc}$

Where

Q_2 = measured quadrupole frequency

Q_0 = coherent tune

δQ_{inc} = incoherent tune shift

a_x = horizontal beam dimension

a_y = vertical beam dimension

Hardware - Quadrupole Oscillations

Possibilities for the Pickup

- Collaboration with Jansson et al
- Resonant QMM, extension of the LF Schottky pickup
- IPM

Of these the IPM is particularly attractive:

- IPM is in the baseline, no new hardware/software
- Need working IPM anyhow for the width measurement
- Quadrupole oscillation measurement already shown in RHIC
- Opens the possibility of measuring variations in incoherent tune shift along the length of the bunch - e cloud diagnostic?

Kicker - BIG pulser driving BIG kicker in quadrupole mode

QMM BTF – Chanel (from GSI? CERN?)

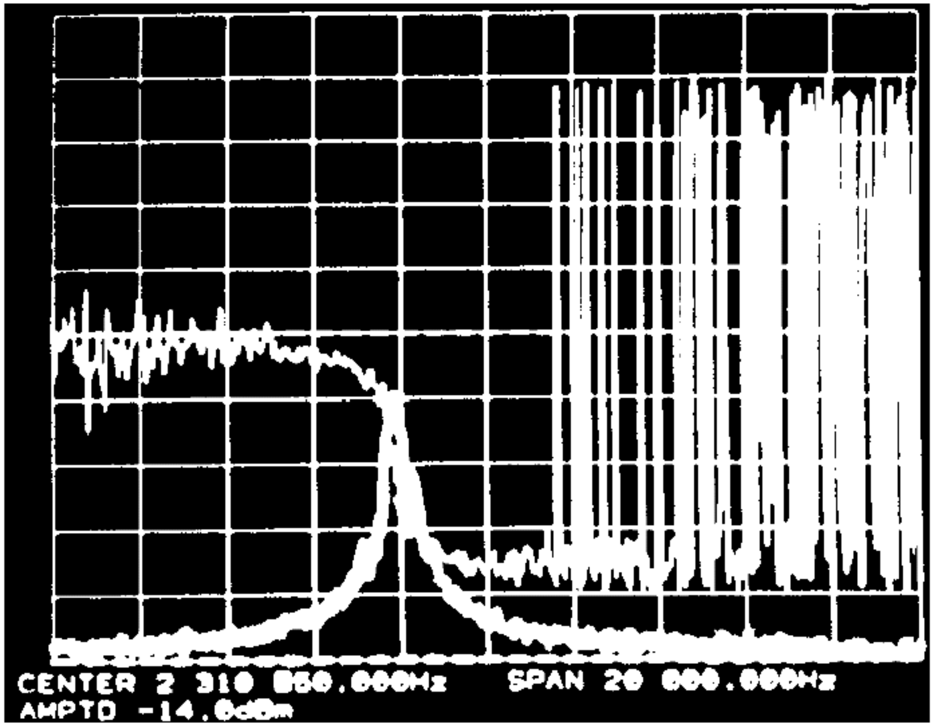

Fig. 1: Typical amplitude and phase of the Q-BTF in the vertical plane at $(3\text{-}2q_v)f_{rev}$. f_{rev} = 1.197 MHz, q_v = 0.577, $\Delta q_{v,inc}$ = -0.06.

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Summary and Conclusions

- Tune control is crucial for low-loss high-intensity operation
- Tune control implies tune measurement
- Tune measurement is fun
- There are 3 basic approaches
  - Coherent - big kick
  - Schottky and quasi-Schottky - no kick or non-perturbative kick
  - Quadrupole oscillations
- All approaches will be investigated, and it is reasonable to hope that all can be implemented (or essential groundwork can be laid at the least) with present budget and manpower limits